

Millimeter Wave Scalar Stimulus Response Up to 325 GHz

By
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Abstract

A novel mixer based scalar stimulus response (MSSR) is described. The stimulus millimeter wave signal is generated using a multiplier and microwave synthesizer. The response is down converted to an Intermediate Frequency (IF) using external millimeter wave harmonic mixers. The response is shown on microwave spectrum analyzers. The signal generator power and frequency are controlled by the spectrum analyzer. The system can be used to cover the complete waveguide band up to 325 GHz. Dynamic range, noise floor, speed and cost of the MSSR System is compared to the vector network analyzer (VNA) and detector scalar network analyzer (DSNA).

1. Introduction

Millimeter wave frequencies, 30 to 300 GHz are of great interest for communications, transportation, scientific research and homeland security because of the unique effects of the atmosphere on transmission channel characteristics. Millimeter waves are attenuated by the atmosphere at different rates for different frequencies. Frequencies where gaseous absorptions are a minimum are called atmospheric windows (35, 94, 140, and 220 GHz). Regions of maximum absorption are called absorption bands (60, 120, and 182 GHz). Millimeter wave applications that operate in atmospheric windows and absorption bands include satellite communications at 60, 94 and 140 GHz, scientific research at 220 and 240 GHz, imaging and homeland security at 94 GHz and automotive radar at 76, 94 and 140 GHz.

Test techniques for components, networks or systems in these bands can range from highly accurate characterization of amplitude and phase response used for modeling in the early design stage, to magnitude only go/no-go testing in volume production or operational support. Test solutions also range in performance and price. High-end vector network analyzers provide the most complete and accurate characterization, while scalar network analyzers and home-brew source/receiver solutions are adequate for many applications where performance can be traded off for lower cost.

A new solution is proposed in this paper that provides better performance than scalar network analyzers at a much lower cost than vector network analyzers and can be assembled using existing microwave instrumentation with millimeter wave accessories. A new source control option in a high performance spectrum analyzer working in conjunction with a high performance signal generator, external harmonic mixers and millimeter wave multipliers allows fast automatic swept stimulus response measurements to 325 GHz.

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2. Vector and Scalar Network Analyzers

A network analyzer is an instrument or system used to make stimulus response measurements on analog and digital devices and systems. A signal is generated and connected to the input of the device under test (DUT) then the output or reflection of the DUT is measured. A vector network analyzer (VNA) can characterize the phase and magnitude, while a scalar network analyzer (SNA) measures magnitude only. The VNA is typically a tuned receiver with a high sensitivity front end. The dynamic range of the VNA is excellent, and the measurement speed is very good and the phase information allows high order (vector) error correction providing best accuracy.

An SNA often costs less than a VNA and provides useful measurements for applications where phase information is not needed and ultimate accuracy is not critical. Detectors are used to measure the output of the DUT and the SNA is used to display the device performance. There are significant challenges to making SNA measurements at millimeter wave frequencies due to the method used for generating millimeter wave signals as shown in Section 3.

In this paper we introduce a “Mixer based Scalar Stimulus Response” (MSSR) that is distinguished from the detector-based SNA (DSNA) by its use of a down converter in the receiver path and detection at an IF frequency rather than at a millimeter wave frequency. This novel approach overcomes many of the challenges and provides additional measurement capabilities not typically available in an SNA.

3. Generating Millimeter Wave Signals

The source in the MSSR System uses multiplication techniques to generate millimeter wave signals from microwave sources (≤ 20 GHz). Table 1 shows millimeter wave waveguide bands, the current designation, band frequency ranges, and waveguide inside dimensions (in mils). Rectangular waveguides work in the Transverse Electrical Dominant Mode (TE_{10}), and each band has a cut off frequency as shown in Table 1. Below this cut off frequency, millimeter waves cannot propagate into the waveguide. Waveguide bandwidths are typically around 50% and it is strongly recommended to work below TE_{20} or twice the cut off frequency of the waveguide band.¹

TABLE 1: WAVEGUIDE BANDS AND CHARACTERISTICS

WG Band	Current Designation	Frequency in GHz	Cutoff Frequency in GHz	Dimension in Mils
WR-15	V	50-75	39.87	148 x 74
WR-12	E	60-90	49.35	122 x 61
WR-10	W	75-110	59.01	100 x 50
WR-08	F	90-140	73.77	80 x 40
WR-06	D	110-170	90.84	65 x 32.5
WR-05	G	140-220	115.75	51 x 25.5
WR-04	Y	170-260	137.52	43 x 21.5
WR-03	J(H)	220-325	176.71	34 x 17

Multiplied microwave signals can cover all of the required bands, and the millimeter wave output frequency specifications are directly related to the microwave input signal characteristics. Table 2 shows the multiplication factors from OML, Inc.^{1,2} for the standard waveguide bands from WR-15 to WR-03. As shown in Table 2, doubling and tripling are used for generating millimeter wave signals. As an example, to generate a 270 GHz signal, a 15 GHz signal would be multiplied by 18 (double, tripled, tripled) and if the resolution of the 15 GHz input signal was one MHz, then the resolution of the 270 GHz output signal 18 MHz.

Table 2: Multiplication Factors for Millimeter Wave Sources

Frequency Range GHz	Waveguide Band	Multiplication Factor
50-75	WR-15	4 (2x2)
60-90	WR-12	6 (2x3)
75-110	WR-10	6 (2x3)
90-140	WR-08	8 (2x2x2)
110-170	WR-06	12 (2x3x2)
140-220	WR-05	12(2x3x2)
220-325	WR-03	18 (2x3x3)

4. Detector Scalar Network Analyzers (DSNA)

In DSNA systems a detector is used to capture the magnitude of millimeter wave signals. Depending on the system used, DC or AC detection is chosen. Detectors usually respond to all signals within the waveguide range because it is not a tuned receiver. Thus, the system dynamic range is dependent on the signal purity of measured millimeter wave signals, and it is susceptible to noise and overload conditions.

For example, the W-band input signal of 12.5 – 18.33 GHz and multiplication factor of 6 generates a frequency band of 75 – 110 GHz. However the fifth harmonic of 62.5 - 91.6 GHz ,seventh harmonic of 87.5-128.3 GHz and the eighth harmonic of 100-184.1 GHz are also generated with lower values (<= 15 dBc). All of these signals are detected by the DSNA system, and the unwanted signals degrade the accuracy as well as the dynamic range.

In order to increase the DSNA dynamic range, a set of filters (low pass or high pass) may be used to eliminate the unwanted signal within the measurement range. But any loss in the passband of the filters directly reduces the system dynamic range, so there is limited improvement for higher millimeter wave frequencies. Thus, a new method is needed for measurement without using the filters.

5. Microwave Spectrum Analyzer with External Harmonic Mixers

The receiver in the MSSR System is a microwave spectrum analyzer with a harmonic mixer. A spectrum analyzer is a tuned receiver with user-settable resolution bandwidth providing immunity to unwanted signals and noise with very high dynamic range. A harmonic mixer is used to down convert the signal of interest to the measurement range of the analyzer. Many spectrum analyzers offer an external mixing option that provides an LO output and an IF input. The LO output is used to drive to the external harmonic mixer and the external mixer IF output is connected to the analyzer IF input. In this application

the LO frequency range is 3-7 GHz and the IF is 321.4 MHz. Table 3 shows frequency ranges with associated harmonic numbers for external harmonic mixers.^{2,3}

Table 3: External Mixers Harmonic Numbers

Frequency Range GHz	Waveguide Band	Harmonic Number
50-75	WR-15	14
60-90	WR-12	16
75-110	WR-10	18
90-140	WR-08	22
110-170	WR-06	26
140-220	WR-05	32
220-325	WR-03	48

6. Mixer Based Scalar Stimulus Response (MSSR)

A new external source control option available for microwave spectrum analyzers represents a turning point for the millimeter wave scalar analysis, providing complete mixer-based scalar stimulus response without the need for any filters. Figure 1 shows a block diagram for this system. The spectrum analyzer controls the signal generator so the multiplied output signal is coordinated with the measurement. The analyzer displays the DUT performance measured at the IF output of the external harmonic mixer. The MSSR allows use of the normal measurement features of the spectrum analyzer e.g. RBW, number of points, span, marker, start, and stop. Stimulus response measurement can run continuously or in single sweep mode without the need for an external computer, and amplitude correction for the flatness and conversion loss of the test system is automatically applied, and the scalar measurement errors are removed.

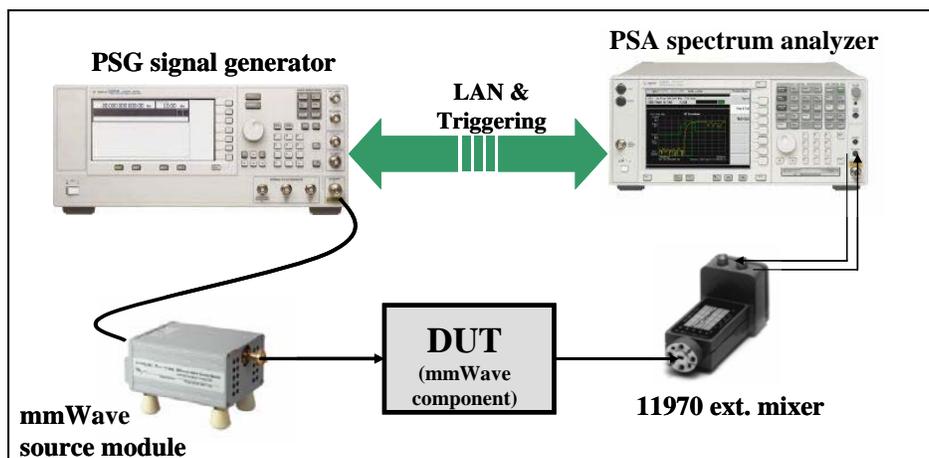


Figure 1. MSSR system overview

7. Detail Solution Descriptions

Figure 2 shows the detail setup for the scalar stimulus-response solution up to 110 GHz. The trigger out, RF Reference out and sweep out of the Agilent PSG signal generator are connected to the trigger in, RF Reference in and sweep in of the PSA Series high-performance spectrum analyzer. A LAN

line is also connected between the PSG and the PSA. The millimeter wave source module interface is connected to the rear of the PSG. The RF output of the PSG drives the source module to produce the millimeter wave frequency in the range of the output waveguide (in this example it is W-band, 75-110 GHz). The isolator is used to buffer the output of the DUT to the input of the external harmonic mixer. The LO and IF are connected between the PSA and the external harmonic mixer.

For millimeter wave frequencies above 100 GHz to 325 GHz, Figure 3 shows the detail connections and model numbers for the PSG and the external mixers. Figure 4 shows the solutions between 50 and 110 GHz.

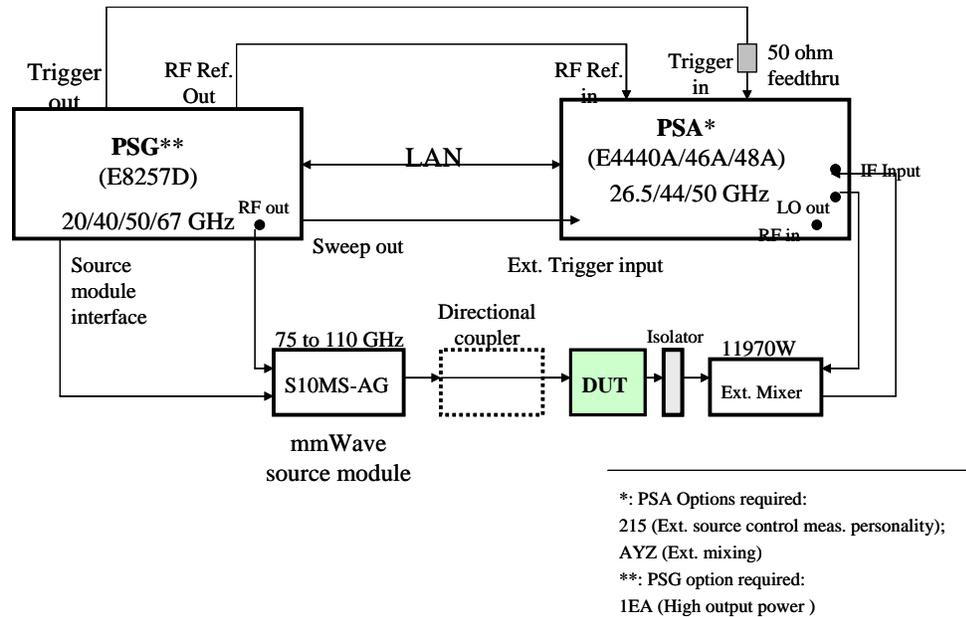


Figure 2. Detailed block diagram for the MSSR setup

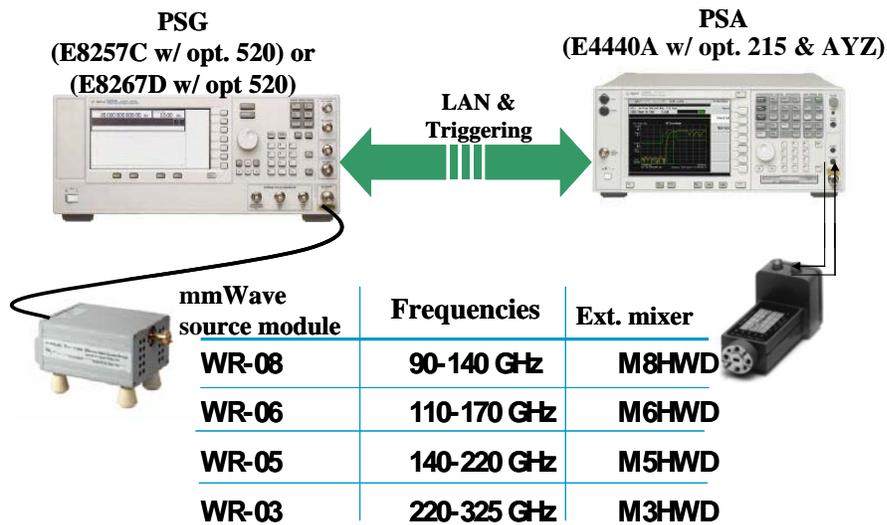


Figure 3. MSSR setup for frequencies between 110 GHz and 325 GHz

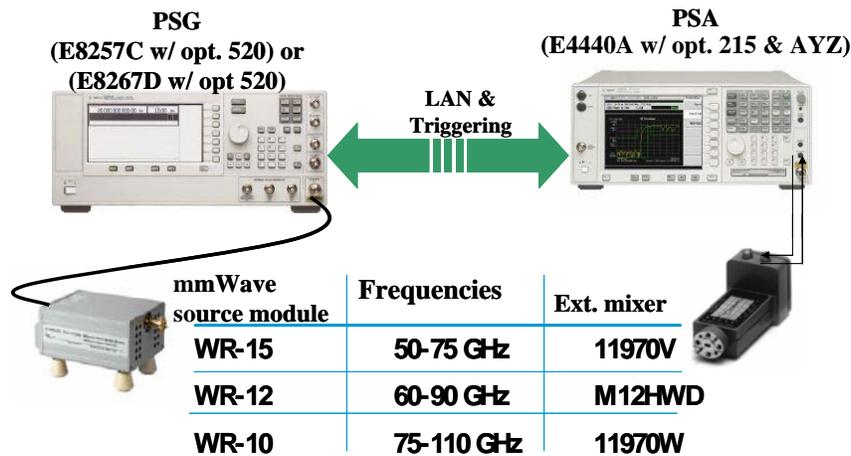


Figure 4. MSSR setup for frequencies between 50 GHz and 110 GHz

8. Examples Using This Solution

8a. Transmission of Band Pass Filters (80-100 GHz)

Figure 5 shows the transmission characteristics of a millimeter wave band pass filter across the 75-110 GHz range. As shown, a dynamic range of over 70 dB is realized using this solution.

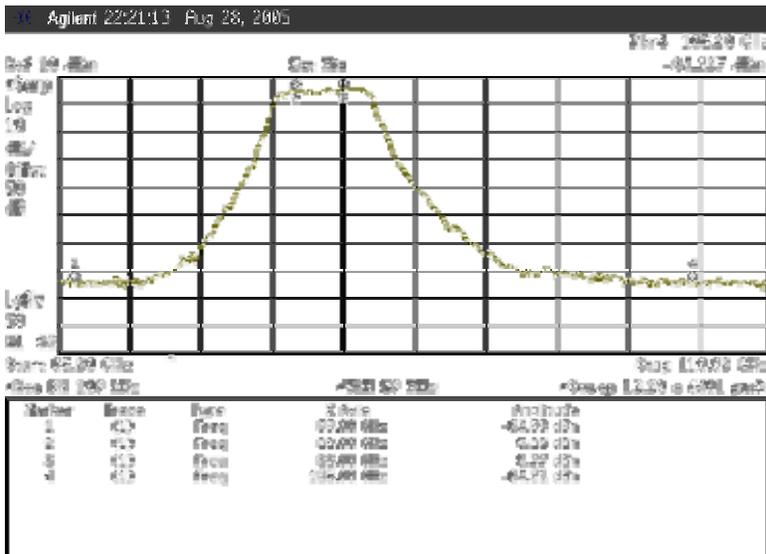


Figure 5. PSA display for the transmission characteristic of a band pass filter

8b. Reflection and Transmission of Band Pass Filters (80-100 GHz)

Figure 6 shows a block diagram where the number of channels is increased from 1 to 3 using an automated switch box and a dual directional coupler with 3 millimeter wave harmonic mixers. Figure 7 is the display for the reflection and incident power to the band pass filter.

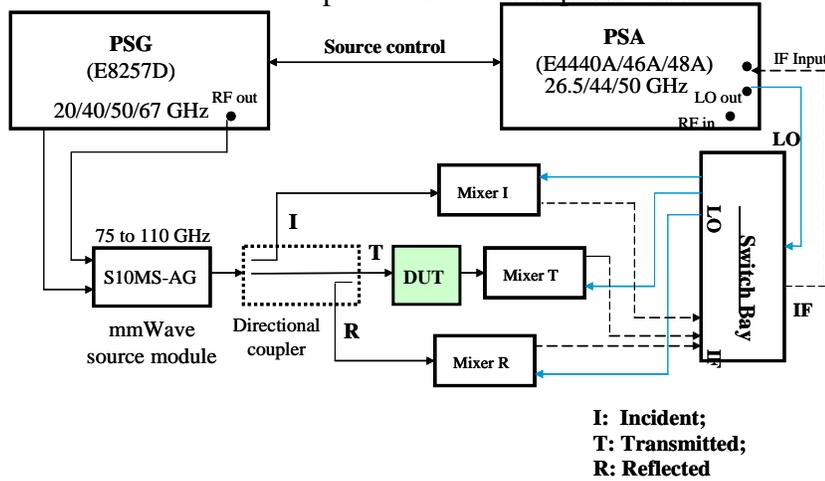


Figure 6. Three channels MSSR setup using a switch bay

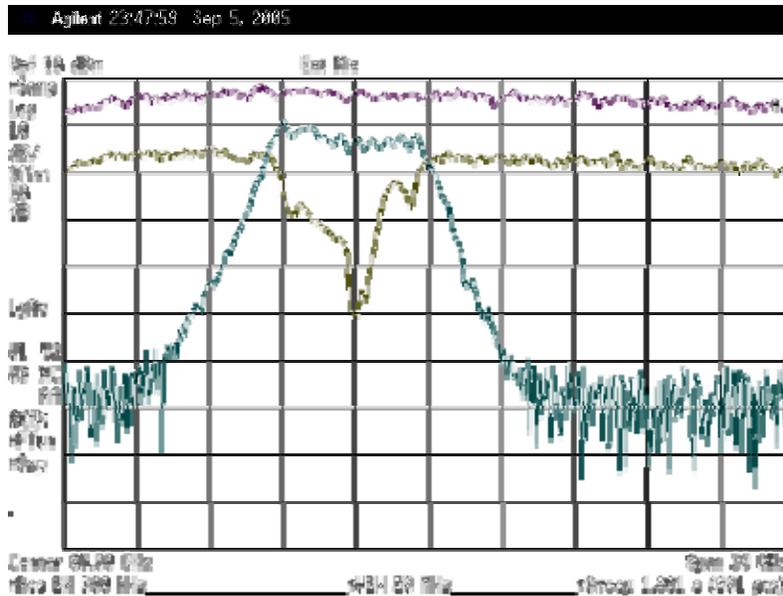


Figure 7. PSA display for the Incident, transmitted, and reflected signals

9. Specific Applications for the Solution

9a. Multipliers

Stimulus can be swept from f_1 to f_2 and the response can be measured from $N(f_1 - f_2)$ where $N = 1$ to 20.

9b. Mixers

Stimulus signals can be applied to the input, LO applied to the mixer and the output IF can be measured in the millimeter wave range using this solution.

9c. Amplifiers

Amplifier gain and return loss can be measured using this stimulus response solution. Real time amplifier tuning of input and output matching can also be achieved with this solution. The harmonics of an amplifier can also be measured as described in Section 9a.

9d. Attenuators

Fixed or variable attenuators can be tuned or measured using this stimulus response solution.

9e. Couplers & waveguide sections

Coupling factor insertion loss of coupler and waveguide sections can be measured using this stimulus response solution

10. Advantages of the Solutions

Some of the solution advantages can be stated as follows:

10a. The need for a filter is eliminated since the harmonic mixer technique is frequency selective.

10b. There is flexibility to use one or multiple harmonic mixers as needed. This will deliver the optimum solution to the user.

10c. Existing PSA and PGA equipment can be re-used. Thus, users need to only acquire multipliers and harmonic mixers in the frequency range of interest.

10d. Newer and improved harmonic mixers can be used. Thus, the system performance will also improve.

11. Limitations of the Solutions

11a. Only magnitude can be measured. If phase measurements are needed, then a VNA must be used.

11b. Only scalar corrections can be used. Thus, the accuracy of the measurements will be less than when using a VNA.

11c. A switch box needs to be used to increase the number of channels to be more than one.

12. Comparison Between VNA, SNA, and MSSR

Figure 8 shows the comparison between VNA, SNA and MSSR in chart form. The parameters are: frequency range, dynamic range, cost, accuracy, measurement time and upgradeability.

13. Conclusions

- Easy usage of standard microwave PSA and PSG with the waveguide components of the appropriate band.
- Utilization of PSA firmware features in the millimeter wave range.
- 10 – 20 dB better performance than DSNA up to 325 GHz.
- 50 – 70 % lower cost than VNA up to 325 GHz (scalar only).
- Flexibility of using the appropriate number of external harmonic mixers to assemble specific test systems and applications.

14. Acknowledgements

The authors would like to acknowledge the help from OML, Inc. for supplying the millimeter wave components discussed in this paper. We also want to recognize the invaluable assistance received from Jim Zeller and John Noble from Agilent Technologies during the course of technical discussions.

15. References

1. OML, Inc., Morgan Hill, CA, www.oml.mmw.com
2. Agilent Technologies, Inc., Palo Alto, CA. www.agilent.com
3. Mohamed Sayed, *Millimeter Wave Tests and Instrumentation*, 65th ARFTG Conference Digest, June 2005.